Rolling Back the Gains: Maternal Stress Undermines Pregnancy Health After Flint's Water Switch

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Abstract:
Environmental disasters impact disadvantaged communities disproportionately both through the epidemiological challenge of exposure, but also by undermining the progress of public health efforts. This paper studies changes to smoking cessation, breastfeeding, and weight gain during pregnancy in the period following the switch in water supply in Flint, Michigan, in April 2014. As the switch resulted in immediate and significant deterioration in water quality, eventually leading to its contamination with lead, we estimate a 10.5 percentage point increase in smoking and a 2.1 percentage point decrease in breastfeeding. We show evidence that these changes in maternal behavior are linked to increased stress due to changing water quality. We estimate that the increase in smoking alone is responsible for most of the increase in incidence of low birthweight among infants in Flint, resulting in $700 additional costs per birth. Increased smoking during pregnancy and lower breastfeeding rates in Flint roll back years of public health efforts, resulting in lifetime higher rates of cardiovascular disease, diabetes, and cancer for mothers in the community.

Keywords:
Health behaviour, health and poverty, population health, public services, environmental health and safety, pollution control, environmental protection and regulation

JEL Codes:
H12, H41, I12, I14, Q51, Q52, Q58

1 Introduction

In Flint, Michigan, a city which has been considered a Medically Underserved Area (MUA) since 1984, pregnancy presents a critical opportunity to change maternal health and lifestyle. More generous Medicaid coverage, combined with frequent screenings for chronic conditions such as diabetes and hypertension, and an active encouragement to adopt a healthier lifestyle constitute a low-cost public health intervention impacting not only the mother's future health, but also infant health. It is, therefore, particularly important to understand how public health emergencies, such as the water contamination in Flint, affect choices pregnant women make during pregnancy and at birth. This paper evaluates the impact of the water contamination in Flint on maternal pregnancy behaviors.

Flint is particularly vulnerable to stressors from environmental pollution, as its housing stock is less well-maintained, with many homes close to factories, refineries, and highways. Residents in the community are less able to engage in avoidance behavior or exposure mitigation. Even when aware of the danger associated with exposure to contaminants, families in Flint have little ability to change housing, move to a better neighborhood, or renovate premises. At the same time, however, poor households are more vulnerable to the financial burden of the medical expenditures associated with exposure. The combined effect of pollution, lack of mitigation, and financial vulnerability translate into chronic anxiety and stress culminating in a lifetime of health conditions.

This research examines pregnancy outcomes for mothers in Flint in the period after the residential water supply in the city was switched to Flint River, which we refer to as the "water switch". Though the eventual contamination of water with lead became known more than a year after the switch, the quality of the water changed immediately and multiple boil advisories were issued due to bacterial contamination in the months after the switch. Because of the uncertainty surrounding the periods of bacterial and lead contamination, in this study we examine pregnancies which were conceived after the water switch. The focus on this study is the cumulative effect of living in Flint

after the water switch on pregnancy behaviors which, we believe, operate through the awareness, anxiety, and stress. Furthermore, we believe that these mothers did not plan pregnancies around the water switch.

Flint is a unique case study in contamination for two reasons. First, though Flint is not the only city to struggle with water quality and lead levels, it was the only city during this time period in Michigan to experience a sudden change in water quality, as even communities immediately outside the city limits were not affected by the switch. Second, the time period of water quality concerns studied in this paper was sufficiently short to preclude families selectively moving out of the area.

Using the universe of recorded births in Michigan from 2013 to 2015 we find a 10.5 percentage point (pp) increase in continued smoking among women who previously smoked, a 20% increase on the average in Flint. Maternal smoking is associated with additional $700 in neonatal costs per birth (Adams et al., 2002). Pregnancy is a critical time to quit smoking, and this missed opportunity translates into a lifetime of increased risk of cardiovascular diseases, the leading cause of death for women in Flint.[1] We also find a 3.9 pp decrease in initiation of breastfeeding, but a 5.4 pp increase in intent to breastfeed, generating a net 2.1 pp decrease in eventual breastfeeding. We find modest, but not robust, increase in pregnancy weight gain.

This research has two main contributions. First, we focus on maternal health. Beyond infancy, pregnancy is the period of greatest developmental change for women. As mentioned above, pregnancy is both a great opportunity for a positive health intervention, as well as a great risk to future health. Such opportunities and risks are particularly important in communities with poor access to health care and high rate of chronic conditions. Second, the data used for analysis allows us to link maternal residence to the nearest lead measurement. In addition to a difference-in-differences analysis between cities, we conduct within Flint analysis using the nearest lead measurement as a

[1] "Age-adjusted Death Rates for Ten Leading Causes by Sex Flint City, Genesee County, Michigan Residents, 2015" Accessed April 6, 2020.

proxy of intensity of stress at the household level. Combined with a rich set of covariates, our estimates allow us to measure the impact of maternal stress resulting from the water quality changes on pregnancy behaviors.

As environmental pollution declines over time under stricter policy, stress is likely to be a more prominent adverse impact of contamination. This research provides evidence of changing maternal behavior resulting from stress of potential exposure. Such changes in maternal behavior often reverse years of incremental gains in smoking cessation and breastfeeding, highlighting an understudied effect of environmental contamination on communities struggling to improve population health.

Before discussing this paper's contribution to literature, estimation method, data, and results, the next section will describe the timeline of the Flint water contamination to motivate the choice of exposure time period. The presentation of results will be followed by a discussion of the findings.

2 Flint Water Contamination

As part of the fiscal restructuring of Flint, the emergency manager appointed to the city by the governor mandated a switch of water supply from Detroit Water and Sewerage Department (DWSD) to the Flint River, as an alternative supply pipe from Lake Huron was in planning stages. Despite repeated warnings of lack of preparation of the Flint water treatment facility, the switch was effectuated on April 25, 2014 (M. Kennedy, April 20, 2016).

Immediately after the switch, residents complained of changes to quality of water, citing color, odor, and taste; the Michigan Department of Environmental Quality (MDEQ) repeatedly assured residents about the safety of the water supply citing transitional adjustments. In the summer of 2014, high levels of e.coli and total coliform bacteria were detected, prompting water boil advi-

sories, and increased chlorine level in water. In January 2015, city water was cited in violation of the Safe Drinking Water Act because of high levels of total trihalomethanes (TTHM), a disinfectant byproduct which occurs when excessively high level chlorine interacts with organic matter in the water. TTHM did not return to safe levels until September 2015. Though the high chlorine level precluded bacterial contamination, the water treatment facility failed to add appropriate anti-corrosives to the water, resulting in erosion of residential pipes in the city, exposing century old lead joints. Lead leached from these joints into the water supply.

In February 2015, city tests detected the first instance of high lead levels in a residential home. These results were labeled as outliers by the city authorities, and residents were assured of the safety of the water. At the same time, a group of researchers from Virginia Tech began systematic testing of residential water lead levels in Flint. Their report was released in August 2015, showing average lead levels as high as 19 times the 15 ppb limit set by the Environmental Protection Agency (EPA). At the same time, Hanna-Attisha, LaChance, Sadler, and Champney Schnepp (2016) from Hurley Medical Center in Flint found a 1.9 percentage point increase in high blood lead level in children under 5 compared to before the water switch. By the end of September 2015 Flint issued a lead advisory to residents, and switched the water supply to Detroit.

3 Literature on Environment and Maternal Health

This research contributes to three distinct bodies of literature. First, it contributes to the quasi-experimental literature on maternal pregnancy stress. Second, it contributes to the sizable epidemiological literature of the effect of pollution on pregnancy and maternal health. Finally, it contributes to the growing literature on the effect of Flint water contamination.

3.1 Maternal Stress

While exposure to water contaminants, including lead, may have a significant impact on pregnant women, we believe a major mechanism is through the psychosocial environment created by the water quality on residents of Flint. As such, this research contributes to the extensive literature on maternal and infant outcomes following stressful pregnancy conditions. This literature includes effects of physical violence (Currie, Mueller-Smith, & Rossin-Slater, 2018), maternal grief (Black, Devereux, & Salvanes, 2016), employment (Wust, 2015), and Ramadan fasting (van Ewijk, 2011). Fuller (2014), Currie and Rossin-Slater (2013), and Simeonova (2011) estimate the negative effects of natural disasters on pregnancy outcomes. Physiologically, pregnancy stress has been associated with low birth weight and earlier delivery (Lobel, Dunkel Schetter, & Scrimshaw, 1992), and increased likelihood of depressive symptoms in the postpartum period for both parents (Dunkel Schetter, Saxbe, Cheadle, & Guardino, 2016; Saxbe et al., 2015). Webb, Siega-Riz, and Dole (2009) find evidence of relationship between depression and gestational weight gain, but find no similar relationship with stress and anxiety. Cuthbertson, Newkirk, Ilardo, Loveridge, and Skidmore (2016) document increasing levels of stress, anxiety, and depression among residents of Flint in the post-switch period.

3.2 Lead and Pregnancy

While this study addresses the wider effects of water quality, there is substantial research on effects of exposure to lead during pregnancy. While lead is known to affect pregnancy health even at low levels of exposure (Canfield et al., 2003; Jusko et al., 2008; Lanphear et al., 2005; Menke, Muntner, Batuman, Silbergeld, & Guallar, 2006; Navas-Acien, Guallar, Silbergeld, & Rothenberg, 2007; Tabacova, Little, Balabaeva, Pavlova, & Petrov, 1994; Takser, Mergler, & Lafond, 2005; Tellez-Rojo et al., 2006, 2004), the precise mechanisms of the effect are unclear. Exposure to high and low levels of lead is associated with spontaneous abortion (Anttila & Sallmen, 1995; Hertz-

Picciotto, 2000; Laudanski et al., 1991; Lindbohm et al., 1992; McMichael et al., 1988; Murphy et al., 1990; Tabacova & Balabaeva, 1993). Lead is a known risk factor for hypertension among adults, though the effect is less clear during pregnancy. D. Kennedy, Woodland, and Koren (2012) review nine studies of blood lead level and perinatal hypertension, finding positive association in six of those studies. Gestational diabetes can develop among pregnant mothers with no previous history of diabetes, and poses a threat to health through pre-term birth, larger infants at birth, and higher incidence of diabetes later in life for mother; studies have found no significant association between lead exposure and gestational diabetes (Peng et al., 2015; Shapiro et al., 2015). In terms of exposure, Currie, Zivin, Meckel, Neidell, and Schlenker (2013) and DiSalvo and Hill (2019) establish that ingestion of contaminants through drinking water has health effects similar to other forms of exposure, such as other forms of oral ingestion (i.e. paint chips) or inhalation.

3.3 Flint Water Contamination

A number of studies in recent years have analyzed the health and socioeconomic changes in Flint resulting from the contamination. While Hanna-Attisha et al. (2016) showed evidence of increasing average blood lead levels (BLL) among children in Flint, Zahran, McElmurry, and Sadler (2017) linked rising BLL to the contamination. Abouk and Adams (2018) found a lower average birthweight and increasing incidence of low birthweight after the contamination. Sauve-Syed (2017) links the contamination with fewer students scoring proficient in math and reading among elementary- and middle-school children.

Media reports at the time highlighted the effect of the water contamination on lives of residents, emphasizing the anxiety and stress in the community (Funes, 2016; Kounang, 2018). Christensen, Keiser, and Lade (2019) show evidence of socioeconomic changes, as home prices decline during the contamination. Grossman and Slusky (2019) use birth and fetal death record data to estimate the impact of the Flint water contamination on gross fertility rate as well as infant health at birth.

Our work builds on Grossman and Slusky (2019) as our analysis focuses on pregnancies which have resulted in a live birth.

4 Data

We use Vital Statistics birth records data from the state of Michigan for all births between 2013 and 2015. These data contain information about the birth date, infant and birth characteristics, parental characteristics, maternal prenatal behavior, maternal perinatal health outcomes. Parental characteristics include maternal age, race, and whether the mother completed high school. Maternal health includes indicators for pre-pregnancy diabetes and hypertension, gestational diabetes and hypertension, method of birth, and presence of infections. Maternal behaviors of interest in this study are continued smoking through pregnancy, intend to breastfeed, and weight gain. The data also contains geocoded addresses at which the mother resided at the time of birth. We link the address to the nearest water lead measurement collected by the group from Virginia Tech to obtain an indication of intensity of exposure during pregnancy.

To remain consistent with previous literature, we compare Flint to 15 largest cities in Michigan following Grossman and Slusky (2019). The comparison cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming, shown in the map on top panel of Figure 4. We test the robustness of our results by choosing alternate control cities, as well as subgroups of counties across the state.

5 Method

The time period of interest, 2013-2015 coincides with a number of state-wide economic changes. In 2014, as part of the Affordable Care Act (ACA), Medicaid eligibility was expanded to 138% of federal poverty level (FPL), extending eligibility to non-parental adults. The simultaneous launch of health exchanges allowed access to affordable private health insurance to many Michiganders. During that time Flint was still under emergency management, undergoing other administrative changes. Thus, simply comparing Flint to other cities across Michigan would not capture state and year specific changing trends. To adjust for these common changes we will employ a difference-in-differences (DID) estimation framework, comparing Flint before and after April 2014 to other localities across Michigan. We will estimate:

$$Y_{imy} = \alpha + \beta Pregnancy_i + X_i\gamma + \mu_i + \nu_m + \kappa_y + \epsilon_{imy} \tag{1}$$

where $Pregnancy_i$ is an indicator of birth conceived in Flint after April 2014. We estimate conception week by subtracting estimated gestational age from date of birth. X_i a vector of maternal characteristics such as age, race, and education, and payer type (Medicaid, self-pay); μ_i are census tract fixed effects; ν_m and κ_y birth month and year fixed effects, respectively. In addition to these demographic characteristics, some specifications include pregnancy characteristics: pre-pregnancy maternal health indicators including hypertension, diabetes, smoking, previous cesarean, and an indicator for first birth; pregnancy characteristics include indicators for gestational hypertension, gestational diabetes, and maternal transfer during delivery, and count of infections and prenatal visits. Standard errors, ϵ_{imy} are clustered at census tract, city, or county level, as appropriate. Because Flint is the only treatment unit, usual clustering methods may underestimate standard errors. To correct for this bias, we also estimate standard errors using bootstrap with heteroskedasticity correction method developed by Ferman and Pinto (2019) .[2] Furthermore, we perform robustness

[2]We also estimate standard errors using wild bootstrap method as described by Cameron, Gelbach, and Miller (2008), with similar estimates

checks using randomized inference testing.

The outcomes we study, Y_{imy} are some which, we believe, are susceptible to behavioral choices by women, including continuing smoking, intent to breastfeed, and weight gain. All models are estimated with ordinary least squares, including linear probability models for indicator variables.

We depart from the Grossman and Slusky (2019) by defining exposure using conception (as opposed to birth) in Flint after April 2014. Our choice is conditioned by the uncertainty around the time when water quality started changing noticeably. Residents reported changing color and odor of water in the months after switch, and boil advisories were issued in the summer months of 2014. Therefore, it is not clear whether births occurring in the months after the water switch were exposed to the stress stemming from the quality changes, motivating us to use conception after April 2014 as treatment. However, we test the sensitivity of our main findings by estimating effects by trimester of exposure and and by estimating a specification using births after April 2014.

6 Results

6.1 Water Quality

Before proceeding with the results, we would like to present evidence that water quality was, indeed, a concern for residents in the period after water supply was switched. To explore the concern of Flint residents about the quality of municipal water, beyond media coverage, we use Google Trends to track queries using terms which would be associated with such concerns.[3]

Figure 1 shows volume of searches for three terms: "water treatment", "water color", and "lead"

[3]Google Trends query data has been previously used to track social awareness. See Chalfin, Danagoulian, and Deza (2019), Aguero and Beleche (2017), among others.

on a weekly basis between January 2013 and December 2015.[4] We compared search volumes in Flint[5], to those in Michigan, and US. To smooth weekly variation, the results are presented as two-week moving averages.

The top panel in Figure 1 shows searches for "water treatment". While there appear to be a rise in searches in fall 2013, post April 2014, we see a surge in searches starting in fall 2014, continuing through summer 2015. Searches then peak in September 2015 as news of the lead contamination become known. Before treatment becomes a concern, however, searches for "water color" clearly show a sharp rise after the switch. Searches increase steadily through summer and fall of 2014, peaking in April 2015. Almost as a mirror image to the "water color", searches for "lead" see no discernible change in pattern after April 2014, with only seasonal variation. In September 2015, while searches for "water color" decline, those for "lead" surge, reflecting the resolution of uncertainty about water quality.

These search results show that beyond the lead contamination, concern about water quality and color was persistent and high in the entire period after the water switch. Furthermore, these searches also show lack of awareness about the lead contamination by residents of Flint until September 2015.

6.2 Maternal Characteristics

Table 1 presents unadjusted maternal characteristics in control cities before (1) and after (2), and in Flint before (3) and after (4) the switch. Column (5) presents the unadjusted DID comparing Flint to other cities after the switch.

The unadjusted means comparison does not show many statistically significant differences be-

[4] We chose terms which in our view best reflected the types of searches residents would conduct faced with uncertain quality of water. We analyzed a wider range of terms, however these three terms shows the most stark contrast.

[5] More precisely, the smallest geographic unit allowed by Google Trends was "Flint-Saginaw-Bay City, MI".

tween Flint and elsewhere among mothers, with a few exceptions. Black mothers make up a slightly larger proportion in Flint after the switch. Mothers in Flint are also somewhat less likely to have hypertension before the pregnancy. Given the estimates of declining fertility by Grossman and Slusky (2019), we will explore potential changes in maternal composition at birth stratifying our findings by maternal race, age, education, and infant gender. More notably, however, the unadjusted differences show that Medicaid is less likely to be the primary payer for births in Flint after the contamination. The net decline in Medicaid enrollment, however, is driven primarily by a sharp rise in Medicaid enrollment in the control group. The period of the water switch coincides with the roll out of ACA mandated Medicaid expansion. While the expansion did not affect pregnancy coverage, the welcome mat effect, as described by Frean, Gruber, and Summers (2017) may be stronger in control cities which start at lower participation levels. In Flint, about 85% of all births were covered by Medicaid in the pre-period, suggesting a smaller pool of eligible but unenrolled mothers.

6.3 Main Results

We start by examining changes to maternal behaviors estimating specification 1 for outcomes of interest: smoking while pregnant, intent to breastfeed, and weight gain during pregnancy. Table 2 presents estimation results for the three outcomes, starting with a baseline specification in column (1), and adding pre-pregnancy health indicators (column (2)) and delivery health indicators (column (3)). In each specification standard errors are clustered at city level. The preferred specification in column (3) also reports p-values for standard errors estimated using bootstrap with heteroskedasticity correction method developed by Ferman and Pinto (2019) to account for single treated group.[6]

Estimates show a 10.5 pp increase in smoking while pregnant in the sample of women who

[6]We also estimate standard errors using wild bootstrapping using Cameron et al. (2008), with very similar results.

smoked before pregnancy. Before the water switch of mothers in Flint who smoked before pregnancy 52.6% continued to do so while pregnant, thus our estimate represents a 20% increase. After birth, we estimate a 1.5 pp increase in initiation or intent to initiate breastfeeding. On a base of 74% of births in Flint in the pre-period, this constitutes a 2% effect. In Appendix A7 we decompose this effect into mothers who initiated breastfeeding and those who intended to initiate breastfeeding. While the water switch caused 5.5 pp increase in mothers with intent to initiate breastfeeding, there was a 4 pp decrease in mothers who had already initiated breastfeeding. These estimates do not change substantially with inclusion of pre-pregnancy and delivery health indicators, suggesting that selection into motherhood plays a minor role in the observed changes in behavior.

Mothers in Flint also gained 0.39 additional pounds during pregnancy, an estimate which is sensitive to inclusion of pre-pregnancy and delivery health. This specification also includes maternal body mass index (BMI) and infant weight in grams. Despite the statistical significance, however, the increase constitutes a 1.3% increase at the mean, a modest effect.

6.3.1 Intensity of Exposure

To explore the mechanism of stress further, we test the hypothesis that areas more affected by the eventual lead contamination are more likely to see maternal behavioral changes resulting from stress. To test this hypothesis, we match lead measurements across the city of Flint taken by Virginia Tech researchers between January and September 2015 to maternal residential address. Since the measurements were not taken at every residence, we match maternal residence to the closest lead measurement by direct distance. We use measurement at 10 second water flow to reflect levels of lead present in house water pipes, and most likely to be ingested by household members. While lead measurements across Flint vary substantially, we believe the nearest measurement is the best predictor of neighborhood stress associated with changing water quality.

Because we do not have lead measurements across the state, nor in the period prior to the contam-

ination, we estimate an intensity of exposure specification limited to 1,330 pregnancies resulting in birth in Flint after April 2014, that is:

$$Y_{imy} = \alpha + \beta_1 Lead_{imy} + X_i\gamma + \mu_i + \nu_m + \kappa_y + \epsilon_{imy} \tag{2}$$

where $Lead_{imy}$ is the nearest measurement of lead; X_i a vector of parental characteristics such as maternal age and education, and whether Medicaid was the primary payer for birth; μ_i are census tract fixed effects; ν_m and κ_y birth month and year fixed effects, respectively; and ϵ_{imy} error term.

We present the results of estimating 2 in Table 3. The unit of treatment is lead measurement in parts per billion (ppb). While no amount of lead is considered safe, the federally acceptable level of lead in water is under 15 ppb. In our data lead measurements range from 0.32 ppb to 1051 ppb during this period, with mean of 7.57 ppb and median of 1.038 ppb, and over 94% of measurements at or below the federal action level. Thus, while most households in the city experienced lead measurements below actionable levels, the change in water color and quality are still attributed to lead in water. Thus, we use lead measurements as proxies for neighborhood level concern for water quality.

As before, among mothers who smoked, every 10ppb increase in nearest lead measurement is associated with a 1.5 pp increase in probability of continued smoking, 0.4 pp increase in intent to breastfeed, and 0.8lb increase in weight gained. For all three outcomes, the estimates do not change substantially as maternal pre-pregnancy and delivery health characteristics are added. While these results are suggestive, the limitation of the data precludes causal interpretation.

6.4 Sensitivity and Robustness

Though our findings suggest effects of substantial magnitude in smoking, and modest effects in breastfeeding and weight gain, these effects are likely to vary by age, race, and education of the

mother. The weak male infant theory suggests that effects may differ by gender of the infant. Furthermore, though overall weight gain was modest, it may have threshold effects, increasing likelihood of maternal weight gain exceeding the recommended level given pre-pregnancy BMI. We test the sensitivity of estimates by stratifying the sample by age, race, and education of the mother and the gender of the infant, and by testing threshold effects for weight.

Our difference-in-differences specification rests on a number of underlying assumptions about the control group and the pre-period. We conduct additional analyses to test robustness of our estimates to these assumptions. We test our specification for existence of pre-treatment trend between Flint and control cities. Next, we change the control group to examine the effect of this choice on our estimate. Then, we test for spuriousness of our findings by performing a randomized inference analysis. We also explore the role of timing by estimating effect of water switch by trimester of pregnancy, and test alternate fixed effects.

6.5 Weight Gain

To contextualize the pregnancy weight gain during the contamination period, we use Institute of Medicine "Healthy Weight Gain During Pregnancy" recommendations accessed through the Centers for Disease Control and Prevention (CDC) webpage. Using maternal BMI, we define under weight gain and over weight gain consistent with recommended ranges, creating an indicator variable for each mother. The estimates of the main specification using the underweight and overweight gain indicators are reported in Table 4. Our main estimates suggest that we should not see a significant increase in weight gain above recommended levels. The threshold estimates confirm this finding, showing no significant increase in probability of maternal weight gain being above recommended levels. We find a 0.8 percentage point decrease in probability of maternal weight gain being below recommended levels.

Repeating the analysis using nearest lead measurement as a proxy for intensity of exposure to stress, we find a 0.4 pp increase in probability of gaining more than recommended weight and a 0.2 pp decline in probability of gaining less than recommended weight for every 10ppb increase in measured lead.

6.5.1 Stratified Analysis

We next test for asymmetric effects by stratifying results by race (black, white), age (under26, between 27 and 36), and education (high school or less, more than high school), and gender of infant.[7] We report the results in graphical format in Figure 2. Each panel represents results for each type of stratification. The bars represent the coefficient estimate, with 95% confidence interval marked as whiskers around the bar.

The first panel compares outcomes for black and white mothers. We find that the increase in smoking was large and significant for both black and white mothers, while intent to breastfeed was driven by black mothers. Weight gain, however, was starkly asymmetric, with almost 1.3lbs increase among non-black mothers, and no change among black mothers. Combined, this suggests that while black mothers continued smoking through pregnancy, non-black mothers appear to react most negatively to the additional stress of water switch.

The second and third panels compare mothers with more than high school to those with high school or less education, and younger (26 yo or less) to older mothers (27-36 yo). Neither of these stratifications show significant differences between the groups in outcomes. Smoking, weight gain, and breastfeeding appear to move in similar direction for both of these stratifications.

Stratifying by the gender of the infant we found a large significant difference between mothers of male infants and those of female infants in weight gained during pregnancy. After the water

[7] We present results for groups with a large number of observations. Results for other groups are available upon request.

switch mothers with male infants experienced close to 0.6lbs lower weight gain while mothers with female infants gained almost 1.5lbs additional pounds during pregnancy.

6.6 Pretrend Analysis

Our model specification assumes that prior to the intervention, the treatment and control groups had parallel trends in outcome variables. A potential time confounder, for example, could be the municipal bankruptcy in Flint which began 2012. The post-April 2014 changes to maternal health could be the result of a general decline in city health and services resulting from the emergency management. We test this parallel trends assumption by comparing the pre-trend in Flint and other cities by estimating an event-study specification, of the type:

$$Y_{imy} = \alpha + \sum_{i=Q12013}^{Q42015} \beta_{1i} Flint * I_i + \beta_2 Flint + \sum_{i=Q12013}^{Q42015} \beta_{3i} I_i + X_i\gamma + \mu_i + \nu_m + \kappa_y + \epsilon_{imy} \tag{3}$$

where $\sum_{i=Q12013}^{Q42015} I_i$ is a quarterly indicator for conception, with Q1 2014 as the omitted quarter. β_{1i}, β_2, and β_{3i} capture the event study effect, and the coefficient of interest is β_{1i}. Each specification includes demographic, pre-pregnancy and delivery health indicators, and city fixed effects. Weight gain specifications include BMI and infant weight.

Figure 3 presents the estimates of the event study. In each figure, each point represents the difference between Flint and other cities in that quarter relative to the difference in Q1 2014. The 95% confidence interval is indicated by brackets around each point estimate. It is essential to note that while Q1 2014 is the reference category, a pregnancy conceived in that quarter would include at least two trimesters after the water switch, creating potential for behavioral changes.

Figure 3 shows a clear rise in smoking in the quarters following the water switch, with no significant trend before that. In fact, the quarterly estimates show an initial 10 percentage point rise smoking in the first four quarter, and the effect amplifies in 2015 to closer to 20 percentage point

increase.

We do not find a similar clear trend in breastfeeding or weight gain. More specifically, the quarters before the water switch appear to include substantial variability in these two outcomes between Flint and other cities. To explore these trends for potential heterogeneous group effects generating this variability we repeat the event study for weight gain by race (black vs. white) with results presented in Appendix Figure A7. Though non-black mothers experienced the largest increase in weight gain, stratifying quarterly trend by race do not generate a clear pre- nor post-trend.

To explore potential heterogeneity in breastfeeding, we re-define the variable into its component parts, separating results by those who have already initiated breastfeeding from those who express intent to initiate. The event study for this analysis is presented in Appendix Figure A6. The event study shows three notable features: a constant pre-trend in 2013 for both outcomes; a sharp change for mothers who conceived in the first quarter of 2014; slight increase then stabilization of trend at new level through 2014 and 2015. However, most importantly, initiation is moving the opposite direction from intent to breastfeed. We report the estimates the main difference-in-differences specification in Appendix Table A6, which shows a net 3.9 percentage point decrease in initiation of breastfeeding (10% effect), and a 5.4 percentage point increase in intent to breastfeed (14% effect).

6.7 Control Group

To remain consistent with Grossman and Slusky (2019) we selected a control group of 15 cities around Michigan. To test the sensitivity of our estimates we redefine the control group to include other geographic areas. Specifically, we use four other control groups: Genesee county (which contains Flint); Genesee and Saginaw counties; cities in Michigan known for lead in water according to Urban (2018) shown in a map on panel (b) of Figure 4; control cities in main analysis

with addition of Pontiac and Muskegon. Estimates from these four control groups are presented in Appendix Table A8, and show effects of same direction and similar magnitude to those we found in main analysis.

6.8 Randomized Inference

We test for spurious estimates by performing randomized inference (Cunningham & Shah, 2018; Fisher, 1935) by iteratively assigning treatment to each city in the control group and comparing the estimate to that of our preferred specification. Results of this exercise are presented in Appendix Figure A8 for each outcome. For smoking, we find that the Flint estimate is a clear outlier compared to the falsification tests allowing us to reject the hypothesis of spurious estimate. The Flint estimate for intent to breastfeed is also an outlier, increasing our confidence in the non-random nature of this estimate. The estimate for weight gain is much less strong, failing to reject the hypothesis of spurious finding.

6.9 Additional Analyses

Using gestational age and birth date, we estimate effects of exposure by trimester of pregnancy. Results are presented in Appendix Table A10 showing the largest effects in the third trimester, with a significant increase in probability of continued smoking and intent to breastfeed. We interpret these results with caution, however, since 378 women in our sample had only second and third trimester exposure and 300 women had only third trimester exposure in Flint allowing us limited variation in identification of trimester specific effects.

To further address the treatment timing, we also re-estimate the model defining treatment as birth after April 2014. Results reported in Appendix Table A11 report the estimates from that specification, show 12.2 percentage point increase in mothers who continue smoking, and a 0.7 percentage

point increase in intent to breastfeed. These results are similar in magnitude as main effects.

Since we define exposure by month of conception, we also estimate the main specification using conception month and year fixed effects. Results presented in Appendix Table A12 show effects of very similar magnitude and significance as the main estimates.

7 Discussion

Our results point towards a substantial, significant, and persistent increase in pregnancy smoking among mothers in Flint following the water switch. We find a 10 pp increase in continued smoking among mothers who smoked before pregnancy, constituting a 20% increase on the pre-switch levels. While these effects appear to be large, they are consistent with previous literature linking smoking with stress, anxiety, and depression (Cohen & Lichtenstein, 1990; Crittenden, Manfredi, Cho, & Dolecek, 2007; Hauge, Torgersen, & Vollrath, 2012). The decline in quitting smoking constitutes a substantial rollback in pregnancy health gains in Flint. In our data, in 2013, 495 mothers in Flint reported smoking during pregnancy, and of those 89 reported attempting quitting smoking. 20% of those 89 who attempted to quit in 2013 did not do so in 2014 and 2015, or approximately 18 mothers who continued to smoke. Maternal smoking is associated with additional $700 in neonatal costs per birth (Adams et al., 2002).

The long-term effects of maternal smoking during and after pregnancy are well studied. In a review, Olds (1997) reported that pregnancy and postnatal smoking children's health resulted rise in externalizing behaviors starting as early as the pre-school period, persisting through childhood and adolescence. Externalizing behaviors include physical aggression, mood changes, destructive behavior, and arguing, and the effects persist even when controlling for other health confounders such as family structure, income, alcohol use during pregnancy, divorce, and chronic health conditions (Weitzman, Gortmaker, & Sobol, 1992). More recent research has shown that the interaction

of exposure to second hand smoke during pregnancy with the material hardships creates more extensive adverse effects on cognition in socioeconomically disadvantaged households (Rauh et al., 2004). Xu, Bishop, Kennedy, Simpson, and Pechacek (2015) estimate that approximately $167.5 billion in annual health care spending is attributable to cigarette smoking and 15.2% of all Medicaid spending and 3.4% of out of pocket spending is on smoking related care. The persistence in maternal smoking in Flint after the water switch will result in long term health conditions and associated expenditure for households in the city.

Our estimates also allow for improved understanding of the infant birthweight declines estimated by Abouk and Adams (2018). They estimate a 2.73 pp increase in incidence of low birthweight. A recent study by Inoue et al. (2017) estimated maternal smoking during pregnancy associated with 12.1 pp increase in the incidence low birthweight. Our estimate of 20% increase in smoking among Flint mothers is associated with 2.42 pp increase in incidence of low birthweight, which accounts for 88% of the effect estimated by Abouk and Adams (2018). Thus, our results suggest that some, if not most, of the infant outcomes associated with the lead contamination can be attributed to changes in maternal smoking behavior.

We also find a 1.5 pp increase in breastfeeding which, when separated into initiation and intent shows opposing trends: we find a 3.9 pp (10%) persistent decrease in initiation of breastfeeding, but a 5.4 pp (14%) increase in intent to breastfeeding. Breastfeeding intention is a known proxy for other positive maternal characteristics such as knowledge, experience, self-efficacy, and perceived social support, particularly among low-income and disadvantaged women (Humphreys, Thompson, & Miner, 1998; Mitra, Khoury, Hinton, & Carothers, 2004; Persad & Mensinger, 2008). Intent, however, does not translate into actual breastfeeding behavior (Persad & Mensinger, 2008), and only about one-third of mothers who express intent to breastfeed during pregnancy achieve that goal (Perrine, Scanlon, Li, Odom, & Grummer-Strawn, 2012). With this rate in mind, we can conclude that the 5.4 pp increase in intent to breastfeed will translate into about 1.8 pp potential additional initiations. Combining this estimate with actual initiations suggest that the water switch

resulted in a net 2.1 pp decrease in breastfeeding beyond birth. However, rising rates in intent in Flint point towards maternal characteristics predisposing towards positive health choices which are thwarted by environmental obstacles associated with the water switch.

While planned or initiated breastfeeding reached 80.9% among all births in the state in 2015, only 51.9% of mothers in Flint initiated or expressed intent to breastfeed. In this context, a 2.1 pp decline in this measure in this community constitutes a rollback of years of gains in breastfeeding rates. Given the associations between breastfeeding and cancer, diabetes, hypertension, and myocardial infarction, using estimates for increased incidence of these diseases and their annual direct and indirect medical costs, the 2.1 pp decline in breastfeeding among 2,890 mothers who gave birth during the contamination period, would cost the Flint community $31,500 annually when these mothers reach the age of 65 (Bartick et al., 2013).[8] Each of the 57 fewer moms that chose to not initiate breastfeeding during the contamination period in Flint will incur between $1,200-$1,500 addition costs associated with formula purchase.

Our estimate of 0.38 additional pounds of weight gain are marginally statistically significant at conventional levels, and is not robust to testing assumptions. When limited to non-black mothers, however, the estimate is more meaningful in magnitude and significance, at 1.15 additional pounds. Though this change in weight is relatively small in magnitude, Currie, DellaVigna, Moretti, and Pathania (2010) estimate that the presence of a fast food restaurant within half a mile increases pregnancy weight gain by 49 grams, consistent with additional 1.3-4 calories consumed per day. Given these estimates, 1.15 additional pounds in weight gain are equivalent to 15 additional calories per day.[9] In other words, the stress associated with the water switch in Flint had a worse effect on maternal weight than opening of a fast food restaurant in every neighborhood.

Conceptually, our findings bridge the gap between the literature on stress and pollution on maternal and fetal health outcomes. The maternal stress literature links physiological effects of stress

[8] See Appendix A.7.2 for full calculations.
[9] See Appendix A.7.2 for full calculations.

during pregnancy to adverse outcomes for mother and child (Black et al., 2016; Currie et al., 2018; Currie & Rossin-Slater, 2013; Fuller, 2014; Simeonova, 2011; van Ewijk, 2011; Wust, 2015). In turn, the pollution literature links the physiological effect of environmental exposure on maternal and infant health (Anttila & Sallmen, 1995; Canfield et al., 2003; Hertz-Picciotto, 2000; Jusko et al., 2008; Lanphear et al., 2005; Laudanski et al., 1991; Lindbohm et al., 1992; McMichael et al., 1988; Menke et al., 2006; Murphy et al., 1990; Navas-Acien et al., 2007; Tabacova & Balabaeva, 1993; Tabacova et al., 1994; Takser et al., 2005; Tellez-Rojo et al., 2006, 2004). Our results show evidence that environmental disasters also operate through the mechanism of stress to generate behavioral outcomes for individuals who may not have been directly exposed to the pollutant. Such behavioral changes may be responsible for a sizable share of pregnancy health outcomes.

The implications of our findings are twofold. First, the stress associated with a contamination may exceed the footprint of the contamination itself due to fear of exposure and associated changes in daily activities. Though fewer than 5% of households tested in Flint had water lead levels exceeding federal thresholds, we show that behavioral changes were much more widespread. Second, as the intensity of pollution exposure declines through policy interventions in coming decades, stress associated with each such incident is not likely to abate, generating adverse health outcomes even at low levels of exposure. Such incidents are more likely to affect low-income communities, reversing hard-to-form positive health habits.

The main limitation of this study is data. While we presume that the estimated behavioral changes stem from stress associated with the water quality, we do not have any direct data about stress and stress related symptoms in this period.[10] Nonetheless, news coverage in the months after the water switching show increased anxiety and stress among residents of Flint.[11] Combined with the above mentioned literature linking anxiety and stress with increased smoking during pregnancy,

[10]We attempted to use Michigan Behavioral Risk Factor Surveillance System and the American Time Use Survey to identify either symptoms of stress or time spent on household chores involving water, however neither survey had sufficient observations in Flint to allow for geographic identification at that level.

[11]See, for example, "How the Flint Water Crisis Set Back Thousands of Students", "People Take to the Streets to Protest Water Quality", or "Slideshow: Looking Back on Flint Water Crisis"

we believe the mechanism for the effects estimated here is the stress generated by changing water quality.

Maternal selection presents another limitation of this study. Though Grossman and Slusky (2019) find decreased fertility attributable to the lead contamination, we find little or no change in the composition of mothers in our sample as seen in Table 1. Nonetheless, mothers could have moved out of Flint during this period, skewing our results. We explore this further using Medicaid claims filed by the children born to the mothers in our sample, matching city of birth with subsequent zip codes reported for eligibility of benefits. The results reported in Appendix Figure A5 and Table A6 show that though there is movement out of Flint for mothers in our sample, it does not accelerate during the 2014-2015 period. Comparing the sample of moms who subsequently moved out to those who stayed in Flint, we find no notable differences in socioeconomic characteristics or pre-pregnancy health. However, if the change in fertility found in Grossman and Slusky due to exposure to lead is indeed affecting our sample, we should find little or no change in the first few months after water switch. Yet, we also find changes in smoking and breastfeeding behavior in the first quarters after the water switch when water was not yet contaminated with lead. Thus, we believe, the effect we estimate is due to changing behavior rather than selective declines in fertility.

8 Conclusion

The Flint water switch affected adults differently than children. While infants and children were disproportionately affected by exposure to lead, adults were affected primarily by the stress and anxiety generated by changes in water use as quality changed with the switch. Using the Michigan birth records for 2013-2015, we find evidence of increased maternal smoking and decreased initiation of breastfeeding in pregnancies conceived after the water switch. Given the increasingly known health benefits of breastfeeding, for both infant and mother, its decline in a community with an already low rate is a substantial setback, with associated long-term adverse health out-

comes. We also find suggestive evidence that the increase in maternal smoking may be the main driver of increased low birthweight infants in Flint after the contamination.

While environmental contaminations and associated stress and anxiety cannot be fully prevented, our research shows that these events can generate substantial rollbacks in public health initiatives such as breastfeeding and smoking cessation. Effective responses to such contaminations, therefore, must include initiatives to counter such changes in behavior.

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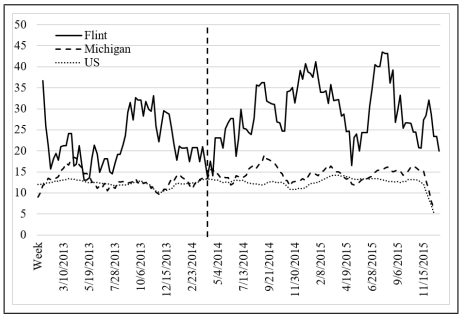
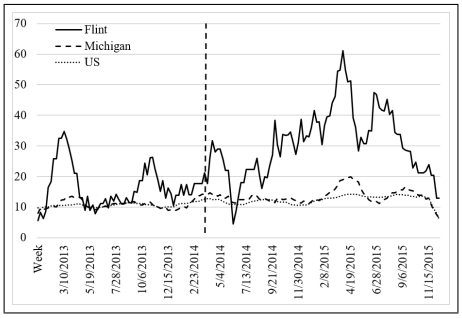
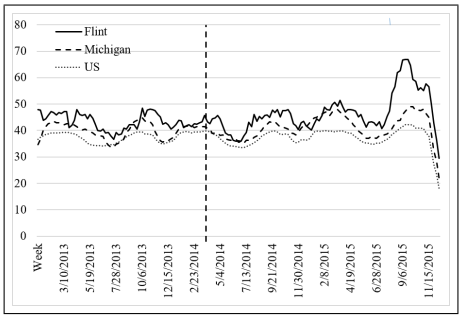


(a) "Water Treatment"



(b) "Water Color"



(c) "Lead"

Figure 1: Google searches for "water treatment", "water color", and "lead" in Flint, Michigan, and the US.

Source: Google Trends 2013-2015. The index is generated by dividing the number of searches for the term by the total searches within the specified geography and time range and, therefore, represents the relative popularity of the term. The resulting number is scaled on a range of 0 to 100 based the term's proportion to total searches. Google drops low volume searches, reflecting them as a "0," it eliminates duplicate searches, and filters out searches with special characters.

Table 1: Unadjusted Characteristics, Flint vs. Other Cities

	Control Cities		Flint		Difference
	(1)	(2)	(3)	(4)	(5)
	Before	After	Before	After	-in-Differences
Black	.419	.417	.601	.633	.0335*
	(.493)	(.493)	(.489)	(.482)	(.0165)
Age	27.51	27.79	24.81	25.21	.1137
	(5.938)	(5.827)	(5.465)	(5.316)	(.1972)
High School	.472	.467	.601	.595	-.0001
	(.499)	(.498)	(.489)	(.490)	(.0167)
Medicaid	.470	.529	.873	.868	-.0649***
	(.499)	(.499)	(.332)	(.338)	(.0164)
Self-pay	.014	.017	.006	.005	-.0054
	(.117)	(.131)	(.081)	(.072)	(.0040)
Pre-pregnancy Hypertension	.015	.016	.019	.012	-.0081†
	(.121)	(.127)	(.137)	(.112)	(.0042)
Pre-pregnancy Diabetes	.008	.008	.015	.018	.0025
	(.088)	(.091)	(.121)	(.133)	(.0030)
Mother Smoked	.169	.158	.305	.284	-.0102
	(.374)	(.365)	(.460)	(.451)	(.0126)
BMI	27.32	27.57	27.7	27.8	-1.611
	(6.95)	(7.15)	(7.64)	(7.86)	(2.371)
Previous C-sections	.124	.125	.176	.193	.0182
	(.329)	(.331)	(.381)	(.395)	(.0111)
First child	.384	.382	.343	.325	-.0181
	(.486)	(.485)	(.475)	(.468)	(.0162)
No. of Observations	55,135	25,493	3,159	1,328	

Source: MDHHS Vital Statistics, 2013-2015.

*** Significant at 0.1 percent level. ** Significant at 1 percent level. * Significant at 5 percent level. † Significant at 10 percent level.

Sample limited to births with 25 or more estimated weeks of gestation. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. Medicaid reflects the proportion of births where the public health insurance program was the primary payer. Breastfeeding was categorized as positive if mother reported having initiated or indicated intent to initiate breastfeeding at the time of discharge from hospital. Education is an indicator of whether the respondent has high school education or less.

Table 2: Maternal Health: difference-in-differences estimates.

	Smoking			Breastfeeding			Weight Gain		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Flint*After	0.0977***	0.0954***	0.105***	0.0147***	0.0162***	0.0153***	-0.161	-0.190	0.389**
	(0.0189)	(0.0181)	(0.0182)	(0.00261)	(0.00268)	(0.00258)	(0.166)	(0.157)	(0.159)
			[0.00]			[0.00]			[0.00]
Dep Var Mean	0.530	0.530	0.526	0.740	0.741	0.742	29.647	29.659	29.705
Demographics	X	X	X	X	X	X	X	X	X
Health Indicators:									
Pre-Pregnancy		X	X		X	X		X	X
Delivery			X			X			X
Fixed Effects:									
Birth Month and Year	X	X	X	X	X	X	X	X	
City	X	X	X	X	X	X	X	X	
Observations	14695	14667	14155	85284	84828	81513	80446	79908	77637

Source: MDHHS Vital Records, 2013-2015.

*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

Each column is a separate specification, with the dependent variable defined as: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. The treatment is birth conceived in Flint after April 2014. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. All specifications control for birth year, birth month, and city fixed effects. Standard errors are clustered at city level; standard errors for preferred specification also estimated using bootstrap with heteroskedasticity correction method developed by Ferman and Pinto (2019).

Table 3: Intensity of Exposure

	Smoking			Breastfeeding			Weight Gain		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Flint*After	0.0015***	0.0015***	0.0016***	0.00048***	0.00042***	0.00038***	0.0086*	0.0060	0.0087**
	(0.0003)	(0.0004)	(0.0004)	(0.00005)	(0.00006)	(0.00006)	(0.00511)	(0.00484)	(0.00396)
Dependent Variable Mean	0.864	0.864	0.864	0.521	0.522	0.522	31.539	31.566	31.575
Demographics	X	X	X	X	X	X	X	X	X
Health Indicators:									
Pre-Pregnancy		X	X		X	X		X	X
Delivery			X			X			X
Fixed Effects:									
Birth Month and Year	X	X	X	X	X	X	X	X	
Census Tract	X	X	X	X	X	X	X	X	
Observations	376	376	376	1330	1321	1321	1330	1321	1320

Source: MDHHS Vital Records, 2013-2015.

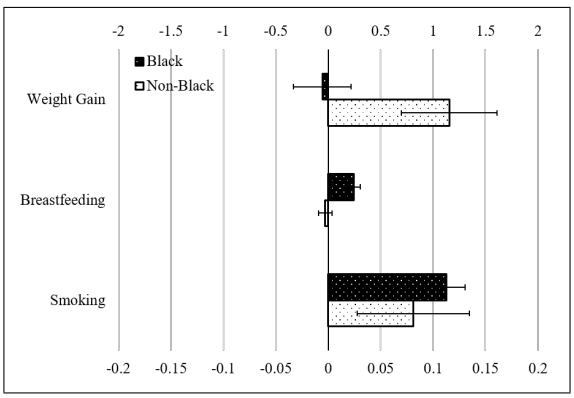
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

Each column is a separate specification, with the dependent variable defined as: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. Sample limited to pregnancies in Flint after April 2014. The treatment is lead measurement at 10 second water flow nearest to maternal residence. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. All specifications control for birth year, birth month, and census tract fixed effects. Standard errors are clustered at census tract.

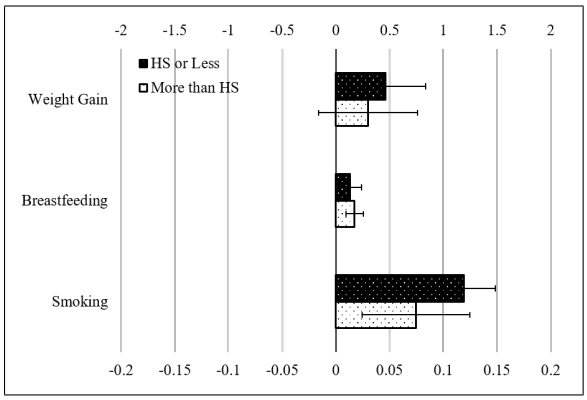
Table 4: Maternal Health: weight gain thresholds.

	Under Weight (1)	Over Weight (2)
Difference-in-Differences		
Flint*After	-0.00879*	0.0107
	(0.00478)	(0.00736)
	[0.100]	[0.400]
Dependent Variable Mean	0.249	0.517
Observations	78105	78105
Intensity of Exposure		
Flint*After	-0.00024***	0.00042**
	(0.00008)	(0.00016)
Dependent Variable Mean	0.236	0.558
Observations	1320	1320
Demographics	X	X
Health Indicators:		
Pre-Pregnancy	X	X
Delivery	X	X
Fixed Effects:		
Birth Month and Year	X	X

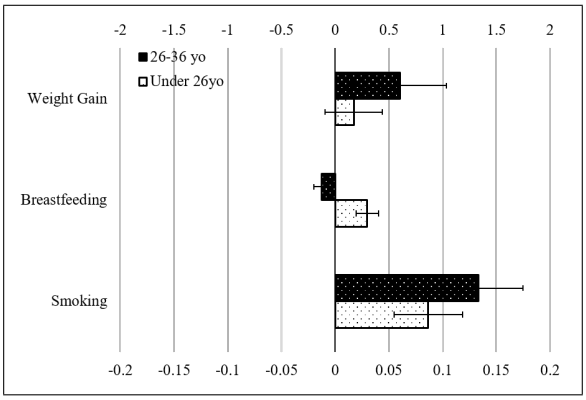
Source: MDHHS Vital Records, 2013-2015.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.
Each column is a separate specification, with the dependent variable defined as: under weight – weight gain below lowest recommended range for women by BMI category; over weight – weight gain above highest recommended range for women by BMI category. The treatment is birth conceived in Flint after April 2014. For DD results, control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. All specifications control for birth year and birth month fixed effects, and city fixed effects. DD standard errors are clustered at city level., estimated using wild bootstrapping. Intensity of exposure standard errors are clustered at census tract level.



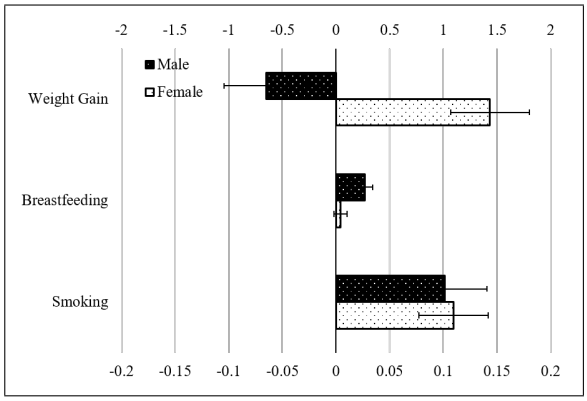
(a) Black vs. white



(b) High school or less vs. more than high school



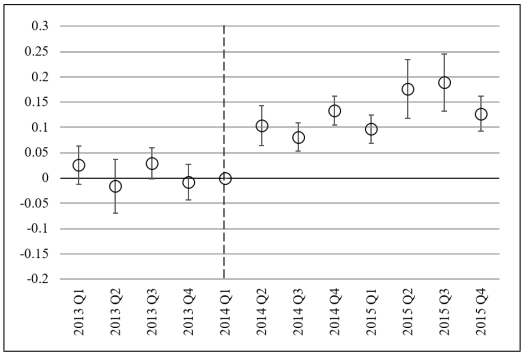
(c) 26 yrs or less vs. 27-36 yrs



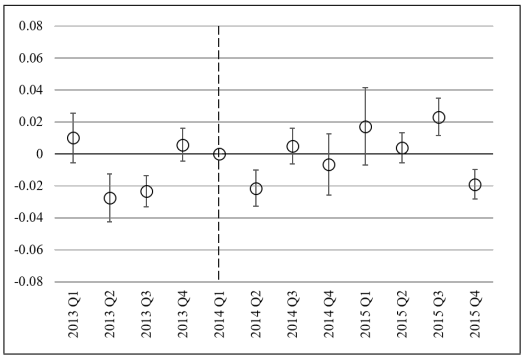
(d) Male vs. female infant

Figure 2: Stratified Analysis

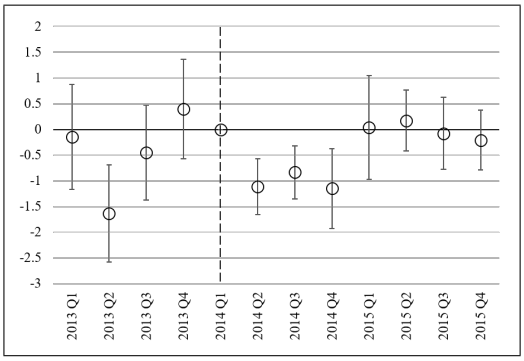
Source: MDHHS Vital Records 2013-2015. Each bar represents estimated DD coefficient of preferred specification for indicated outcome and subpopulation. 95% confidence interval indicated with whiskers around bar. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. The dependent variable for each specification are: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. Each specification includes demographic, payer, pre-pregnancy and delivery health indicators, as well as birth year, birth month, and city fixed effects. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. Standard errors clustered at city level.



(a) Smoking



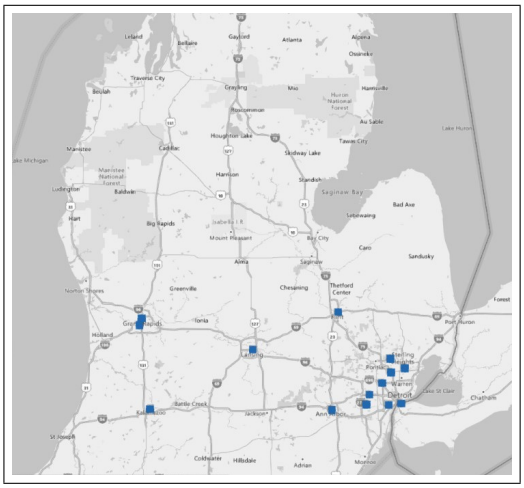
(b) Intent to breastfeed



(c) Weight gain

Figure 3: Pre-trend analysis: quarterly event study

Source: MDHHS Vital Records 2013-2015. Each point represents difference in outcome between Flint and other cities in the indicated quarter, relatively to the first quarter of 2014. 95% confidence interval indicated with whiskers. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. The dependent variables are: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. Each specification includes demographic, payer, pre-pregnancy and delivery health indicators, as well as birth year, birth month, and city fixed effects. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. Standard errors clustered at city level.



(a) Flint and control cities

(b) Flint and cities with known lead issues

Figure 4: Maps of Michigan: Flint and control cities.

Source: Authors' visualization of control cities.

A Appendix

A.1 Flint Compared to Other Cities in the Sample

Table A5: Census tract characteristics: Flint vs. Other Cities.

	Flint			**Other Cities**		
	2013	2014	2015	2013	2014	2015
Female (%)	52.3	52.4	51.8	51.8	51.8	51.8
Black (%)	52.9	54.1	54.6	39.5	39.5	39.5
Under 18 (%)	26.8	26.5	26.2	25.3	25.0	24.7
18-64 (%)	61.8	62.0	62.1	63.1	63.2	63.2 %
65 and over (%)	11.4	11.5	11.7	11.6	11.8	12.1
Insured (%)	86.7	87.5	88.4	84.4	85.0	86.6
Private Insurance (%)	45.6	44.5	43.4	63.9	63.1	62.3
Public Insurance (%)	68.8	69.4	70.3	49.5	50.1	50.9
Labor Force Participation (%)	50.8	51.1	51.9	60.8	60.5	60.4
Unemployment Rate (%)	26.8	26.9	25.1	18.8	17.5	15.7
Poverty Rate (%)	36.3	37.0	37.1	24.0	24.5	24.4
Vacancy Rate (%)	22.5	23.0	24.4	16.2	16.2	16.0
Female Head of Household (%) (of those in poverty)	52.9	51.2	51.4	37.0	37.5	36.9

Source: ACS, 2013-2015.

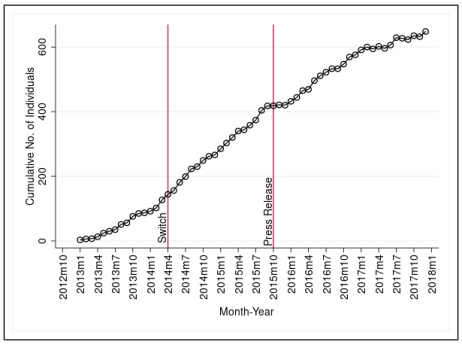
A.2 Selective Movement Out of Flint

Selective movement of mothers out of Flint during our study period would undermine the consistency of the sample used in the analysis. To examine this we combine the birth certificate data for Medicaid eligibility files for all children born in Flint in the 2013-2015 period, and follow their monthly eligibility update from January 2013 through December 2017. Eligibility updates include the zip code of residence of the enrollee which, appended with birth certificate data, allows us to track births in Flint and subsequent registration with Medicaid in a non-Flint zip code.

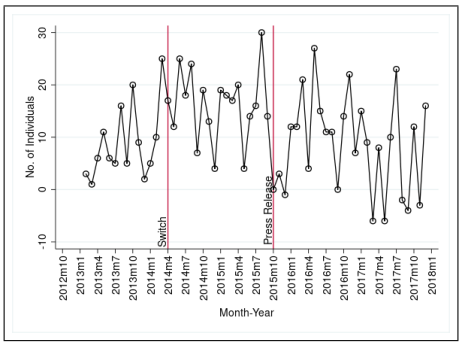
Doing so reveals that during the 2013-2017 period, of the 5847 persons who were born in Flint, 1748 (38.9%) moved out of the city at some time. We start by looking at the cumulative count in number of individuals in our sample who moved out of Flint, presented in panel (a) of Figure A5. On the figure, we have also marked the time of the water switch as well as the time when information about the lead exposure was officially acknowledged in a press release. We see that a steady number of individuals has moved out of Flint in our sample, with no clear visual cues on whether the movement accelerated or slowed after the water switch. Panel (b) shows the same movement but in incremental monthly changes, showing no apparent increase in monthly changes in zip code out of Flint.

In Panel (c), we de-trend the incremental monthly changes, using a linear time-trend estimated in the pre-period, and fitted to the post-period. These de-trended series show, if anything, a decline in movement out of Flint starting in the period after the switch and continuing well past the period analyzed in this study.

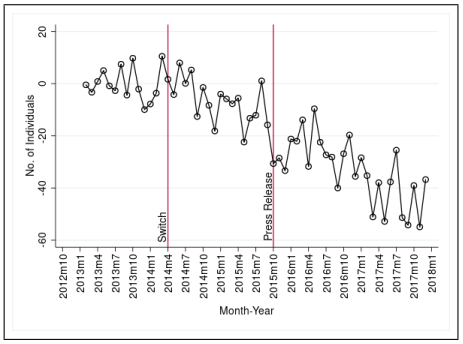
Table A6 summarizes the characteristics of mothers who moved before and after the water switch to those who never moved. Because the movement data is constructed using Medicaid eligibility files, for this analysis, our sample is restricted to low income households. While movers are generally different from non-movers, in particular, they are less likely to be black, more likely to be smokers, and more likely to be having their first child, these differences remained the same after the water switch. Black mothers are a notable difference, as their share among movers decreases after the water switch. Most importantly, however, we do not find any statistically significant differences among mothers who smoke, have high school or higher education, or have pre-pregnancy medical conditions which would explain subsequent selection into breastfeeding or continuing to smoke through pregnancy.



(a) Cumulative movement out of Flint



(b) Monthly movement out of Flint



(c) De-trended monthly movement out of Flint

Figure A5: Movement out of Flint

Source: MDHHS Vital Records 2013-2015 and Medicaid Eligibility Files 2013-2017. Sample limited to births with 25 or more estimated weeks of gestation. Sample limited only to births in Flint. Movers are defined as those who had a maternal residence in Flint at time of birth, and a zip code reported on Medicaid eligibility that were outside of Flint.

A.3 Pre-Trends: Breastfeeding

Though Table 2 shows a modest increase in breastfeeding in Flint after the water switch, the quarterly pre-trend analysis in Figure 3 does not show a clear trend before or after. To explore this

Table A6: Characteristics of Movers and Non-Movers Before and After Switch in Flint

	Non Movers		Movers		Difference
	(1)	(2)	(3)	(4)	(5)
	Before	After	Before	After	-in-Differences
Black	.628	.650	.464	.429	–.057***
					(.016)
Age	24.52	24.72	24.33	24.32	–.211
	(5.266)	(5.329)	(5.028)	(4.894)	(.182)
High School	.599	.617	.602	.607	–.0131
					(.0167)
Self-pay	.0004	.0040	.0117	.0043	–.0109***
					(.0021)
Pre-pregnancy Hypertension	.022	.019	.022	.015	–.004
					(.004)
Pre-pregnancy Diabetes	.016	.017	.001	.012	.009*
					(.004)
Mother Smoked	.310	.296	.352	.337	–.001
					(.015)
Previous C-sections	.183	.178	.163	.176	.018
					(.013)
First child	.329	.326	.348	.376	.031†
					(.016)
No. of Observations	15,017	119,857	938	20,001	

Source: Source: MDHHS Vital Records 2013-2015 and Medicaid Eligibility Files 2013-2017.
*** Significant at 0.1 percent level. ** Significant at 1 percent level. * Significant at 5 percent level. † Significant at 10 percent level.
Sample limited to births with 25 or more estimated weeks of gestation. Sample limited only to births in Flint. Movers are defined as those who had a maternal residence in Flint at time of birth, and a zip code reported on Medicaid eligibility that were outside of Flint.

further, the original data allowed us to separate breastfeeding into initiated (mother indicated that she had already initiated breastfeeding) vs. intent (mother has not initiated but indicated intent to do so). Results from DD specification are presented in Table A7, and the quarterly event study in Figure A6.

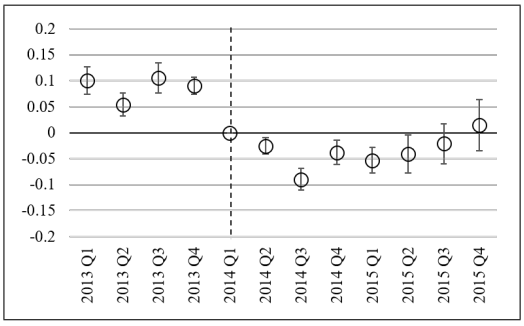
Table A7: Breastfeeding: Initiation and Intent.

	Initiated (1)	Intent (2)
Difference-in-Differences		
Flint*After	-0.0394**	0.0546***
	(0.0171)	(0.0177)
Dependent Variable Mean	0.359	0.389
Observations	80741	80741
Demographics	X	X
Health Indicators:		
Pre-Pregnancy	X	X
Delivery	X	X
Fixed Effects:		
Birth Month and Year	X	X

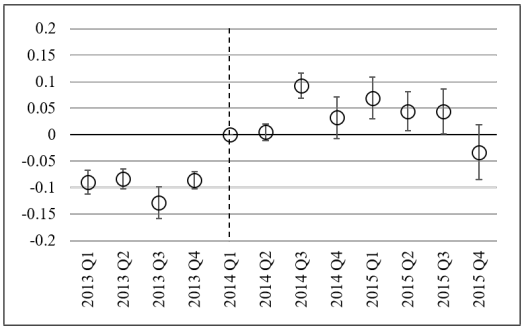
Source: MDHHS Vital Records, 2013-2015.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.
Each column is a separate specification, with the dependent variable defined as: Initiated – mother indicated that she has initiated breastfeeding; Intent – mother indicated that she has not initiated but intends to breastfeed. The treatment is birth conceived in Flint after April 2014. For DD results, control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. All specifications control for birth year and birth month fixed effects, and city fixed effects. Standard errors are clustered at city level.

A.4 Pre-Trends: Weight Gain Among White and Black Mothers

When stratifying analysis by race, Figure 2 shows that white mothers gain more weight during pregnancy in Flint, than black mothers. To explore this effect in greater detail, we repeat quarterly event study for weight gain, restricting the sample of white, then to black mothers. Results are presented graphically in Figure A7.



(a) Initiated



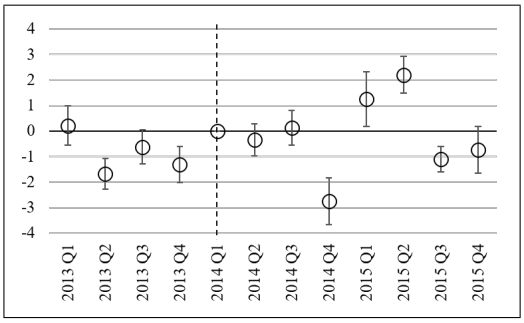
(b) Intent

Figure A6: Breastfeeding: Initiated and Intent

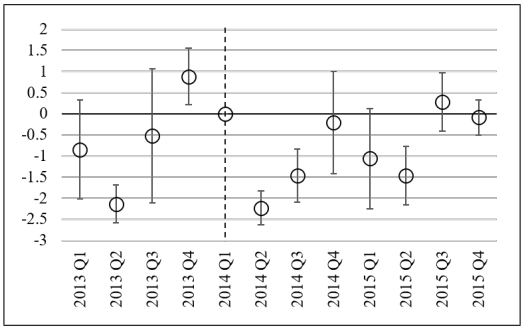
Source: MDHHS Vital Records 2013-2015. Each point represents difference in outcome between Flint and other cities in the indicated quarter, relatively to the first quarter of 2014. 95% confidence interval indicated with whiskers. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. The dependent variables are: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. Each specification includes demographic, payer, pre-pregnancy and delivery health indicators, as well as birth year, birth month, and city fixed effects. Standard errors clustered at city level.

A.5 Randomized Inference

We test for spurious correlation by performing a randomized inference permutation testing (e.g. Fisher, 1935; Cunningham and Shah, 2018) by iterative assigning treatment status to each city in the sample, and estimating preferred specification for each outcome of interest. Resulting coefficient values are presented in Figure A8, with Flint estimate indicated with solid black bar.



(a) White



(b) Black

Figure A7: Pre-Trend in Weight Gain Among White and Black Mothers

Source: MDHHS Vital Records 2013-2015. Each point represents difference in outcome between Flint and other cities in the indicated quarter, relatively to the first quarter of 2014. 95% confidence interval indicated with whiskers. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. The dependent variables are: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. Each specification includes demographic, payer, pre-pregnancy and delivery health indicators, as well as birth year, birth month, and city fixed effects. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. Standard errors clustered at city level.

A.6 Alternative Control Cities

We test the robustness of our estimate to choice of control group by comparing Flint to other cities. Table A8 uses four alternative groups of controls. First, we compare pregnancies in Flint to those in Genesee county outside of the city. The second control group are pregnancies in Sagninaw county and Genesee county outside of Flint. The third control group consists of top 10 cities in Michigan known for presence of lead in water (Urban 2018): Detroit, Grand Rapids, Kalamazoo, Lansing, Wyoming, Battle Creek, Port Huron, Hamtramck, and Saginaw. The fourth control group consists of the cities used in preferred specification with addition of Pontiac and Muskegon.

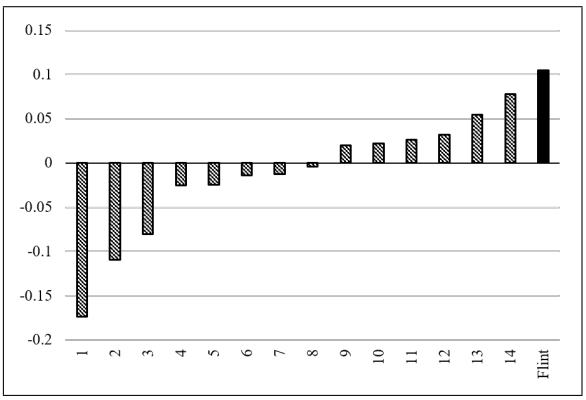
Table A8: Maternal Health: difference-in-differences estimates.

	Smoking	Breastfeeding	Weight Gain
Flint vs. Genesee County:			
Flint*After	0.0721***	0.0342**	-0.0393
	(0.0171)	(0.0151)	(0.466)
Dependent Variable Mean	0.809	0.599	31.854
Observations	1926	7180	7110
Flint vs. Genesee and Saginaw Counties:			
Flint*After	0.0421**	0.0336***	0.316
	(0.0158)	(0.00863)	(0.297)
Dependent Variable Mean	0.721	0.578	30.860
Observations	2750	9706	9613
Flint vs. Top 10 Cities in Michigan with Known Lead in Water			
Flint*After	0.104***	0.0140***	0.323
	(0.0219)	(0.00273)	(0.194)
Dependent Variable Mean	0.568	0.685	28.847
Observations	12723	60076	57422
Flint vs. Control Group and Pontiac and Muskegon			
Flint*After	0.0984***	0.0157***	0.434**
	(0.0169)	(0.00245)	(0.162)
Dependent Variable Mean	0.530	0.738	29.793
Observations	15595	88929	84972
Demographics	X	X	X
Health Indicators:			
Pre-Pregnancy	X	X	X
Delivery	X	X	X
Fixed Effects:			
Birth Month and Year	X	X	X
City	X	X	X

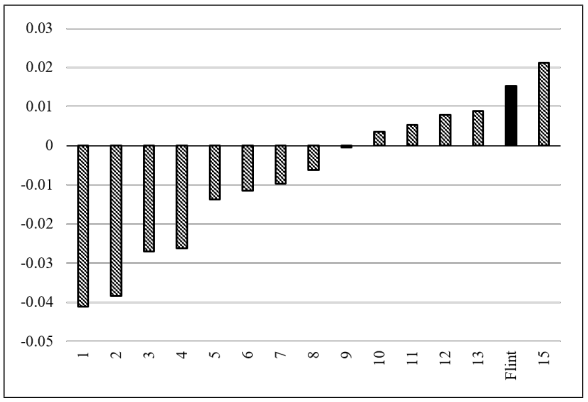
Source: MDHHS Vital Records & ACS 2013-2015.

*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

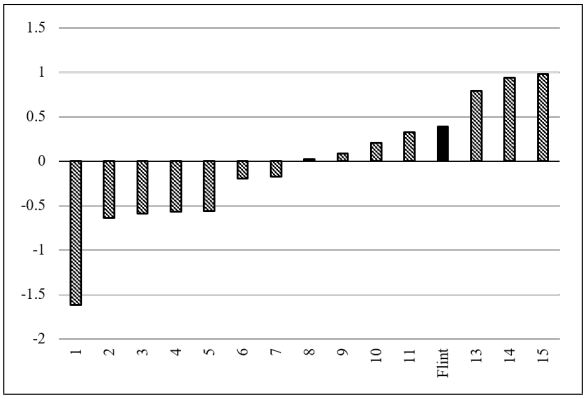
Each column is a separate specification, with the dependent variable defined as: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. The treatment is birth conceived in Flint after April 2014. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. All specifications control for birth year and birth month fixed effects, and census tract fixed effects. Standard errors are clustered at city level.



(a) Smoking



(b) Intent to Breastfeed



(c) Weight Gain

Figure A8: Randomized Inference: Random assignment of treatment

Source: MDHHS Vital Records 2013-2015. Each bar represents difference-in-differences coefficient estimate for preferred specification when treatment is randomly assigned to one of the 15 cities in the sample. In addition to Flint, the cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. The dependent variables are: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. Each specification includes demographic, payer, pre-pregnancy and delivery health indicators, as well as birth year, birth month, and city fixed effects. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. Standard errors clustered at city level.

A.7 Cost Estimates

A.7.1 Calorie estimate

Currie et al. (2010) estimate the caloric impact of a fast-food restaurant within 0.5 miles of maternal residence by converting observed weight gain over the duration of pregnancy to CDC estimates caloric guidelines. Specifically, they estimate that the 49 grams in additional weight gain over 270 days of pregnancy implies 1.3 additional calories a day using CDC estimate that 3,500 additional

calories induce a 1-pound weight increase.

Using the same technique, we calculate that a 3.42 lbs additional weight increase over 270 days of pregnancy translate into 3.42*3500 / 270 = 44.33 additional calories per day.

A.7.2 Health care cost of foregone breastfeeding

Bartick et al. (2013) estimate decrease in incidence of disease per 1000 women for a 15 percentage point increase in breastfeeding, as seen in Table A9. In our sample 2,890 women gave birth, and the estimated decline in breastfeeding intent is 16.3 percentage points. Thus, we estimate the change in occurrence of each condition by multiplying the reported Bartick et al. estimate by $\frac{2890*2.1}{1000*15}$. We estimate the health care costs associated with each disease by multiplying the resulting coefficient by per condition cost reported in Table A9. The reported costs per conditions consist of lower bound, as we selected the costs associated with ongoing care, and not those associated with end of life care. We then sum over all conditions to generate an annual direct and indirect cost of foregone breastfeeding for Flint.

Table A9: Estimates of diseases and associated costs

	Mean Difference With Change from Current to Optimal Lactation		Direct and Indirect Costs
	Cases / 1,000	95% CI	$
Breast Cancer	2.6	(2.1-3.2)	23,863
Ovarian Cancer	0.02	(-0.01 to 0.05)	8,578
Hypertension	28.6	(23.3 - 34.3)	1,096
Type 2 Diabetes	2.4	(-0.42 to 4.3)	4,450
Myocardial infarction	7.4	(3.4 - 11.2)	16,925

Source: Bartick et al. (2013)

A.8 Trimester Analysis

We define exposure by trimester using the birth date and estimated gestational age. The treatment is pregnancy trimester occurring in Flint after April 2014. Trimesters are defined as gestational week 0-12 (trimester 1), week 13-25 (trimester 2), and week 26-36 (trimester 3). The results presented below report the DD coefficients for each trimester. We also estimate our main specification using birth after April 2014 as treatment. Results reported in Table A11.

Table A10: Effects of exposure by trimester of pregnancy

	Smoking	Breastfeeding	Weight Gain
Flint*Trimester 1	0.0910***	–0.0029	1.1720***
	(0.0142)	(0.0043)	(0.2308)
Flint*Trimester 2	–0.0436**	0.0014	-1.8470***
	(0.0118)	(0.0032)	(0.1469)
Flint*Trimester 3	0.918***	0.0084*	0.5524
	(0.0095)	(0.0033)	(0.2834)
Demographics	X	X	X
Health Indicators:			
Pre-Pregnancy	X	X	X
Delivery	X	X	X
Fixed Effects:			
Birth Month and Year	X	X	X
City	X	X	X
Dependent Variable Mean	0.837	0.481	31.871
Observations	14,155	80,741	77,868

Source: MDHHS Vital Records & ACS 2013-2015.

*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

Each column is a separate specification, with the dependent variable defined as: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. The treatment is pregnancy trimester occurring in Flint after April 2014. Trimesters are defined as gestational week 0-12 (trimester 1), week 13-25 (trimester 2), and week 26-36 (trimester 3). Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. All specifications control for birth year, birth month, and city fixed effects. Standard errors are clustered at city level.

Table A11: Difference-in-Differences: Births After April 2014

	Smoking	Breastfeeding	Weight Gain
Flint*After	0.1222***	0.0072*	–0.118
	(0.0118)	(0.0036)	(0.212)
Demographics	X	X	X
Health Indicators:			
Pre-Pregnancy	X	X	X
Delivery	X	X	X
Fixed Effects:			
Birth Month and Year	X	X	X
City	X	X	X
Dependent Variable Mean	0.813	0.479	32.401
Observations	14,155	80,741	77,637

Source: MDHHS Vital Records & ACS 2013-2015.

*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.

Each column is a separate specification, with the dependent variable defined as: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. The treatment is births after April 2014. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. All specifications control for birth year, birth month, and city fixed effects. Standard errors are clustered at city level.

Table A12: Maternal Health: difference-in-differences estimates with conception month and year fixed effects

	Smoking	Breastfeeding	Weight Gain
Flint*After	0.1045***	0.0187***	–0.7151
	(0.0175)	(0.0027)	(0.5517)
Demographics	X	X	X
Health Indicators:			
Pre-Pregnancy	X	X	X
Delivery	X	X	X
Fixed Effects:			
Birth Month and Year	X	X	X
City	X	X	X
Dependent Variable Mean	0.837	0.481	31.871
Observations	14,137	80,685	77,826

Source: MDHHS Vital Records & ACS 2013-2015.
*** Significant at 1 percent level. ** Significant at 5 percent level. * Significant at 10 percent level.
Each column is a separate specification, with the dependent variable defined as: Smoking - indicator for mother who smoked before pregnancy and did not quit during pregnancy; Breastfeeding - mother responded that they have initiated or intend to initiate breastfeeding; weight gain - weight in pounds gained during pregnancy. The treatment is birth conceived in Flint after April 2014. Control cities are Ann Arbor, Dearborn, Detroit, Farmington Hills, Grand Rapids, Kalamazoo, Lansing, Livonia, Rochester Hills, Southfield, Sterling Heights, Troy, Warren, Westland, and Wyoming. Demographic variables include maternal race, age, maternal education, indicators for Medicaid and self-pay as payer; pre-pregnancy characteristics include indicators for pre-pregnancy diabetes, pre-pregnancy hypertension, maternal smoking, previous c-section, and first child; delivery characteristics include number of prenatal visits, indicators for cesarean delivery, maternal transfer, gestational hypertension, gestational diabetes, and number of pregnancy infections. The weight gain specification also includes infant weight in grams, and pre-pregnancy BMI. All specifications control for conception year, conception month, and city fixed effects. Standard errors are clustered at city level.

A.9 Conception Month, Year Fixed Effects

Because exposure to the stress associated with changing water quality did not being immediately upon the switch of supply, the main specification uses conception month for treatment. However, because the data used in this analysis is collected at birth, we use birth month and birth year fixed effects to absorb seasonal and annual variation in births. Here, we re-estimate the main specification with conception month and conception year fixed effects to account for potential cohort effects across treatment and control observations.